

Claims

1. A method of predicting the location of a CDMA mobile communications unit in a wireless communications service area, comprising the steps of:

(a) receiving measured attribute information from a mobile unit location in the service area, said attribute information being specific to the location of the mobile unit in the service area;

(b) computing the probability of the mobile unit being at a specific location in the service area in response to said received attribute information using a likelihood probability function;

(c) generating an output indicative of the likelihood of the mobile unit being at said location in the service area.

2. A method according to claim 1 wherein said likelihood probability function comprises an iterative procedure for producing a maximum likelihood estimator of the mobile unit's location in this service area.

3. A method according to claim 2 wherein the maximum likelihood estimator comprises the coordinates in the service area which maximizes the likelihood probability function.

4. A method according to claim 2 wherein said likelihood probability function comprises a frequentist likelihood function.

5. A method according to claim 2 wherein said likelihood probability function comprises a Bayes-modified likelihood function.

6. A method according to claim 1 wherein said procedure comprises a sequential Bayesian type of procedure.

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1 7. A method according to claim 6 wherein said sequential Bayesian type of
2 procedure uses a frequentist likelihood function.

1 8. A method according to claim 6 wherein said sequential Bayesian type of
2 procedure uses a Bayes-modified likelihood function.

1 9. A method according to claim 1 and wherein said attribute information comprises
2 a pilot signal strength measurement of at least one visible pilot signal at said location of the
3 mobile unit.

1 10. A method according to claim 9 and additionally including a step (d) prior to step
2 (b) of reducing the effective size of the service area so as to reduce the number of
3 computations required in step (b).

1 11. A method of claim 9 and following step (a) and before step (b), additionally
2 including a step (d) of identifying a region A of support for the mobile unit in the service
3 area and (e) identifying a set of possible pilot signals which can be detected by the mobile
4 unit in said region of support.

1 12. A method of claim 11 and additionally including a step (f) of computing an
2 approximation $\tilde{\theta}_{ij}(x, y)$ of the probability the mobile unit detects a pilot signal at said
3 specific location (x, y) in said region A for all pilot signals in said set of possible pilot
4 signals and where j is a sector of a multi-sector base station i in said region of support.

1 13. A method of claim 12 wherein $\tilde{\theta}_{ij}(x, y)$ is derived from an RF model for the RF
2 power $R_{ij}(x, y)$ received by the mobile unit and where the model is of the form of

$$R_{ij}(x, y) = T_{ij} G_{ij}(x, y) L_{ij}(x, y) F_{ij}(x, y) M_{ij}(x, y)$$

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where T_{ij} is the transmit power associated with the sector j of base station i , $G_{ij}(x, y)$ is the antenna gain for the sector j of base station i along the direction pointing towards the location (x, y) within A , $L_{ij}(x, y)$ is the distance loss between the base station i associated with the sector j and the location (x, y) within A , $F_{ij}(x, y)$ is the shadow fading factor and $M_{ij}(x, y)$ is the measurement noise factor.

14. A method according to claim 13 wherein said attribute information comprises the measured visibility of a pilot signal transmitted from a base station and the likelihood probability function comprises an iterative frequentist maximum likelihood (ML) function in the form of

$$L_{ML}^s(x, y) \propto L_{ML}^{s-1}(x, y) \prod_{ij \in K} [\tilde{\theta}_{ij}(x, y)]^{\mu_{ij}^s} [1 - \tilde{\theta}_{ij}(x, y)]^{1 - \mu_{ij}^s}, \quad (x, y) \in A$$

where x and y comprise rectilinear coordinates in the service area A , s is the number of measurement epochs, and μ_{ij}^s is equal to one or zero depending on whether the mobile unit can detect a pilot signal ij at measurement epoch s .

15. A method according to claim 13 wherein said attribute information comprises the measured visibility of a pilot signal transmitted from a base station and the likelihood probability function comprises an iterative Bayes-modified maximum likelihood (ML) estimator in the form of

$$L_{BML}^s(x, y) \propto L_{BML}^{s-1}(x, y) \prod_{ij \in K} \frac{[n_{ij}^{s-1} + \alpha_{ij}(x, y)]^{\mu_{ij}^s} [s - 1 - n_{ij}^{s-1} + \beta_{ij}(x, y)]^{1 - \mu_{ij}^s}}{\alpha_{ij}(x, y) + \beta_{ij}(x, y) + s - 1}, \quad (x, y) \in A$$

where x and y comprise rectilinear coordinates in the service area A , s is the number of measurement epochs, n_{ij}^{s-1} is the number of times a pilot signal in section j of a multi-sector base station i is visible through the first $s-1$ measurement epochs, $\alpha_{ij}(x, y)$ and $\beta_{ij}(x, y)$ are

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11 parameters of a beta distribution, and μ_{ij}^s is equal to one or zero depending on whether the
12 mobile unit can detect a pilot signal ij at measurement epoch s .

1 16. A method according to claim 15 where

$$\alpha_{ij}(x, y) = \begin{cases} 1 & , \text{if } \tilde{\theta}_{ij}(x, y) \leq 1/2 \\ \frac{\tilde{\theta}_{ij}(x, y)}{1 - \tilde{\theta}_{ij}(x, y)} & , \text{if } \tilde{\theta}_{ij}(x, y) > 1/2 \end{cases}$$

$$\beta_{ij}(x, y) = \begin{cases} \frac{1 - \tilde{\theta}_{ij}(x, y)}{\tilde{\theta}_{ij}(x, y)} & , \text{if } \tilde{\theta}_{ij}(x, y) \leq 1/2 \\ 1 & , \text{if } \tilde{\theta}_{ij}(x, y) > 1/2. \end{cases}$$

1 17. A method according to claim 13 wherein the frequentist likelihood function
2 $L_{ML}^s(x, y)$ is combined with a discrete uniform prior distribution for the location of the
3 mobile unit of the form

$$P_{ML}^o(x, y) = \frac{1}{\|A\|}, (x, y) \in A$$

6 to generate a sequential Bayesian procedure which provides a posterior distribution for the
7 location of the mobile unit of the form

$$P_{ML}^s(x, y) \propto P_{ML}^{s-1}(x, y) \prod_{ij \in K} [\tilde{\theta}_{ij}(x, y)]^{\mu_{ij}^s} [1 - \tilde{\theta}_{ij}(x, y)]^{1 - \mu_{ij}^s}, (x, y) \in A.$$

12 where $\|A\|$ is the number of grid points contained within A , and where x and y comprise
13 rectilinear coordinates in the service area A , s is the number of measurement epochs, and

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14 μ_{ij}^s is equal to one or zero depending on whether the mobile unit can detect a pilot signal
15 ij at measurement epoch s .

1 18. A method according to claim 13 wherein the frequentist likelihood function
2 $L_{BML}^s(x, y)$ is combined with a discrete uniform prior distribution for the location of the
3 mobile unit of the form

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$$P_{BML}^0(x, y) = \frac{1}{\|A\|}, (x, y) \in A$$

6 to generate a sequential Bayesian procedure which provides a posterior distribution for the
7 location of the mobile unit of the form

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$$P_{BML}^s(x, y) \propto P_{BML}^{s-1}(x, y) \prod_{ij \in K} \frac{[n_{ij}^{s-1} + \alpha_{ij}(x, y)]^{\mu_{ij}^s} [s - 1 - n_{ij}^{s-1} + \beta_{ij}(x, y)]^{1 - \mu_{ij}^s}}{\alpha_{ij}(x, y) + \beta_{ij}(x, y) + s - 1}, (x, y) \in A.$$

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12 where $\|A\|$ is the number of grid points contained within A , and where x and y comprise
13 rectilinear coordinates in the service area A , s is the number of measurement epochs, n is the
14 number of times a pilot signal in section j of a multi-sector base station i is visible through
15 the first $s-1$ measurement epochs, $\alpha_{ij}(x, y)$ and $\beta_{ij}(x, y)$ are parameters of a beta
16 distribution, and μ_{ij}^s is equal to one or zero depending on whether the mobile unit can detect
17 a pilot signal ij at measurement epoch s .

1 19. A method according to claim 18 where

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$$\alpha_{ij}(x, y) = \begin{cases} 1 & , \text{if } \tilde{\theta}_{ij}(x, y) \leq 1/2 \\ \tilde{\theta}_{ij}(x, y) & \\ 1 - \tilde{\theta}_{ij}(x, y) & , \text{if } \tilde{\theta}_{ij}(x, y) > 1/2 \end{cases}$$

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$$\beta_{ij}(x, y) = \begin{cases} 1 - \tilde{\theta}_{ij}(x, y) & , \text{if } \tilde{\theta}_{ij}(x, y) \leq 1/2 \\ \tilde{\theta}_{ij}(x, y) & \\ 1 & , \text{if } \tilde{\theta}_{ij}(x, y) > 1/2. \end{cases}$$

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1 20. Apparatus for estimating the location of a mobile communications unit in the
2 service area of a wireless communications system comprising:

3 a plurality of base stations and at least one switching center providing a common
4 access to said plurality of base stations;

5 computing apparatus including a memory, electrically connected to at least one of
6 said base stations or said switching center, for storing a set of parameters of a model of the
7 wireless communications system including the RF environment and predicted values of
8 attribute measurement of the service area and wherein the values of the parameters are
9 adjusted to obtain a substantial match between measured attribute values at a predetermined
10 number of locations in the service area and the corresponding initial values predicted by the
11 model;

12 said computing apparatus further including software for calculating, in response to
13 one or more attribute values being measured and reported by the mobile unit from a specific
14 location within the service area, a predicted location of the mobile unit within the service
15 area using a likelihood probability function; and,

16 circuit means coupled to said computing apparatus for generating an output
17 indicative of the predicted location of the mobile unit

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